VERITAS: HAWC's Neighbour to the North

J. Holder[1] for the VERITAS Collaboration[2]

Abstract This paper summarizes a presentation given on the occasion of the inauguration of the High Altitude Water Cherenkov (HAWC) Gamma-ray Observatory in Puebla, Mexico in March 2015. The inauguration of a new facility for the study of astrophysical gamma-rays provides an excellent opportunity to review the technical evolution and the scientific achievements of VERITAS (the Very Energetic Radiation Imaging Telescope Array System) since its own inauguration in 2007. HAWC and VERITAS are separated by only 14° in longitude, and so can view much of the same sky at the same time. In combination with other ground-based facilities, and with the instruments onboard the *Fermi Gamma-ray Space Telescope*, VERITAS and HAWC will give an unprecedented view of the gamma-ray sky. We provide an overview of VERITAS, and discuss the complementarity of the two observatories for future gamma-ray observations.

1 Introduction

VERITAS is an array of four 12-m aperture imaging atmospheric Cherenkov Telescopes (IACTs), sited at the Fred Lawrence Whipple Observatory in southern Arizona. The concept of VERITAS was first proposed by Weekes (1984), in which he described an array of "seven 10-15 m aperture reflectors ... which would ideally be located on a mountain plateau of 3.5 km altitude at spacings of 50-100 m". Following many years of proposal and review, including endorsement by the 2001 Decadal Survey (NRCAASC, 2000), the seven-telescope array was descoped to four telescopes, and funding was secured from NSF, DOE and the Smithsonian Institution. Construction began with a prototype instrument at the Whipple Observatory basecamp in 2003. The full array was completed in 2007, and inaugurated in a "First Light Fiesta" (complete with mariachi band), in April, 2007.

[1]Department of Physics and Astronomy and the Bartol Research Institute, University of Delaware, Newark, DE 19716, USA
[2]http://veritas.sao.arizona.edu

2 The VERITAS Array

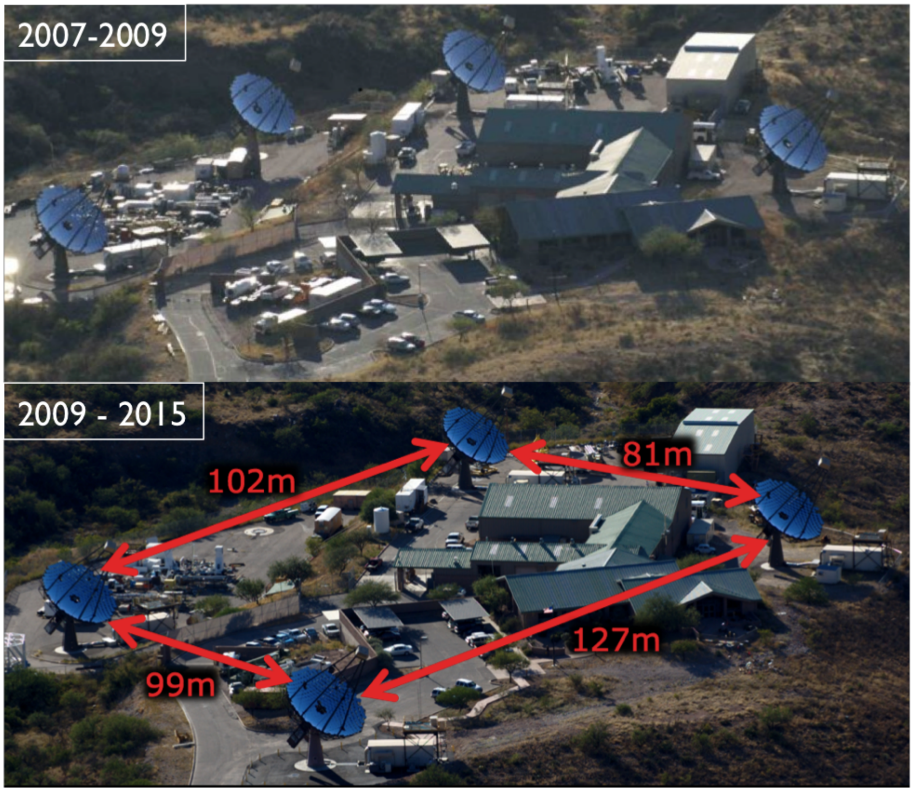

Fig. 1 The VERITAS array, both before and after the relocation of the prototype telescope in summer 2009.

Figure 1 shows the array in its original (top), and present (bottom), configuration. Each telescope comprises a 12 m diameter reflector, assembled from 357 individual facets and instrumented with a 499-pixel photomultiplier tube (PMT) camera (Fig. 2). The mirrors are continually recoated at a coating facility on site. The camera field of view covers a circular region of 3.5°, with 0.15° pixel spacing. Dead space between the pixels is removed by the addition of reflecting Winston cones, which also help to reduce the photon noise due to ambient background light. A three-level trigger system is implemented: the signal from each PMT is fed to constant fraction discriminators, the output of which is used to form a camera-level trigger requiring three adjacent pixels to trigger simultaneously. An array-level trigger requires at least two of the four telescopes to have triggered within a 50 ns window. The data acquisition system is custom-built, and provides 500 MHz sampling of the signals from

all of the PMTs in the array for each event. The telescope positioners are alt-azimuth and, combined with offline corrections from a CCD-based pointing calibration system, allow tracking to an accuracy of around 50 arcsecs.

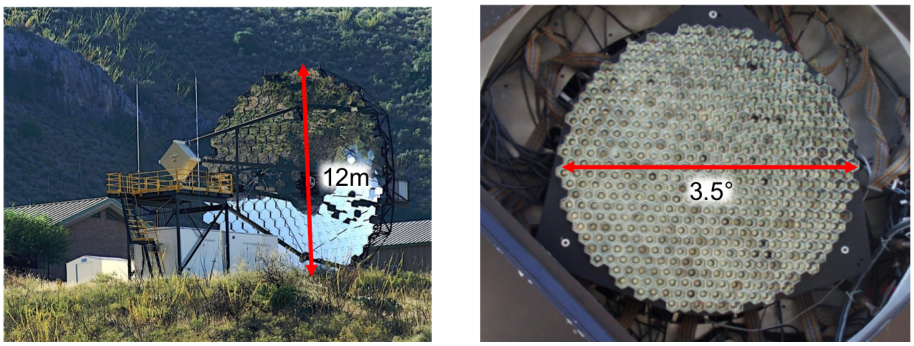

Fig. 2 A VERITAS telescope (left) and 499-pixel PMT camera (right).

The array has undergone a number of significant upgrades since its construction in 2007. The first of these was the relocation, in summer 2009, of the original prototype telescope to a more favorable location in the array. Wider spacing of the telescopes, together with an improved method for mirror alignment (McCann et al., 2010), improved angular reconstruction of the arrival direction of air shower events and reduced the time required to detect a source with 1% of the flux from the Crab Nebula from 50 to 30 hours (Perkins et al., 2009). Due to restrictions on extending the footprint of the array, further upgrades have concentrated on lowering the energy threshold for gamma-ray detection. During 2011-2012, the camera-level trigger systems were replaced with faster, more sophisticated systems, and the array computing network was also replaced. In a major upgrade in summer 2012, all of the camera photo-detectors were replaced with more sensitive "super-bialkali" PMTs, with improved quantum efficiency (Kieda, 2011). As well as further improving the array sensitivity, this has enabled the detection of a number of soft spectrum sources which would not have been possible with the original cameras. It is worth noting that all of the upgrades have been accomplished on time and within budget, and with no loss of observing time.

VERITAS is now completing its eighth season of full array operations. Observations run from mid-September through early July, with a two-month summer shutdown due to local monsoon conditions. While the shutdown adversely impacts observations of Galactic sources, only the shortest nights of the year are lost, and the scheduled break has proven invaluable for equipment maintenance and for upgrades to the array. The observing yield for a typical season is now $\sim$ 1400 hours per year, 95% of which is taken with all four telescopes operating smoothly. The duty cycle has increased by 50% since the start of operations, due to a steady increase in the amount of data taken

under moonlight conditions. Low moonlight observations (with less than 30% of the lunar disk illuminated) comprise typically 165 hours per year, while an additional 300 hours are taken under bright moonlight ($> 50\%$ illuminated), using increased trigger thresholds, reduced gain settings for the photomultiplier tubes (PMTs), or UV-pass filters placed over the telescope cameras.

Data are analysed online with a standard Hillas analysis, providing rapid feedback to the telescope operators. Offline analyses refine the results, prior to publication, and allow to implement more advanced analysis algorithms. Figure 3 shows the performance of VERITAS in its various configurations. Further details are available on the VERITAS web site[1].

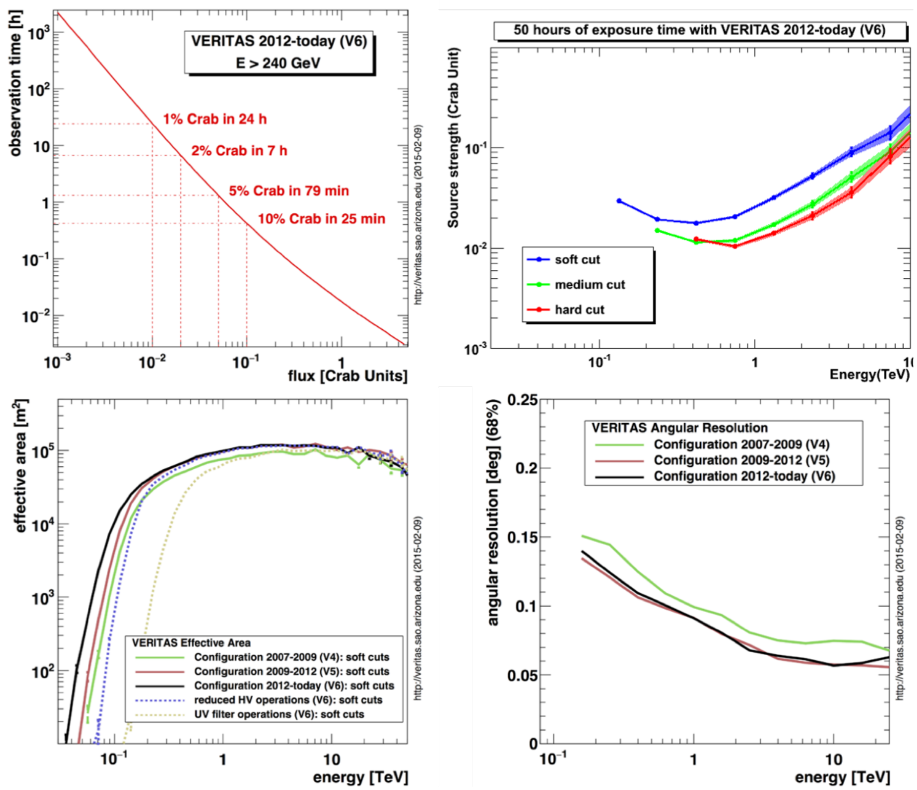

Fig. 3 The performance of VERITAS. Top left shows the time required to detect a source of a given strength with a statistical significance of 5σ. Top right shows the differential sensitivity, for various analysis cuts. Bottom left shows the effective area of the array, in its various configurations. Bottom right shows the angular resolution per gamma-ray event.

[1] `http://veritas.sao.arizona.edu/specifications`

3 Results

At the time of writing, VERITAS has detected and studied 54 sources of astrophysical gamma-rays, comprising one-third of the TeV catalog, roughly half of which were new discoveries. Gamma-rays are observed from at least eight different source classes, implying that efficient particle acceleration can occur in widely different environments throughout the Universe. The gamma-ray horizon due to photon-photon pair production has also proved less of an obstacle than once thought, as highlighted by the recent detection (within the same week by MAGIC (Mirzoyan, 2015) then VERITAS (Mukherjee, 2015)) of a high flux of gamma-ray emission from PKS 1441+25, a flat-spectrum radio quasar (FSRQ) at a redshift of $z = 0.94$. Figure 4 shows the VERITAS catalog in Galactic coordinates. In the following sections we briefly review some highlights from the VERITAS science program.

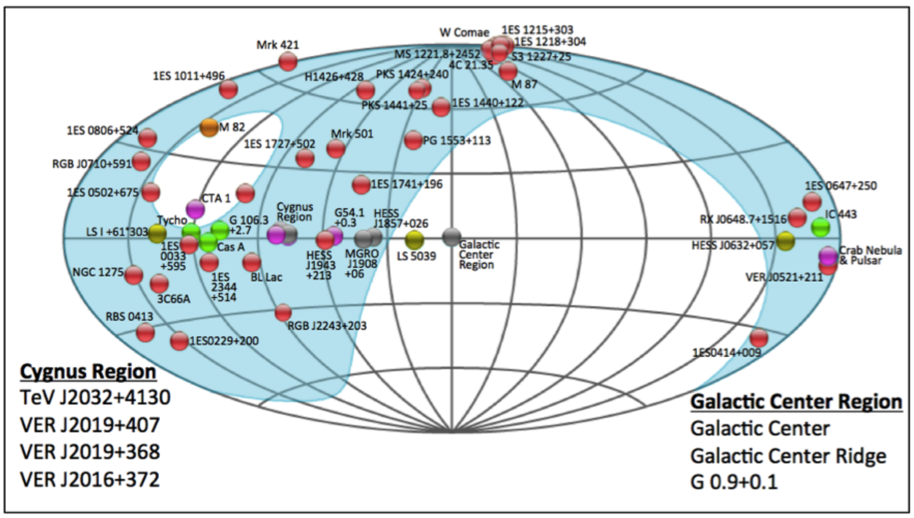

Fig. 4 The VERITAS source catalogue, in Galactic coordinates. The shaded region of the skymap indicates declination from 0° to 60°; sources in this region culminate above 60° elevation for VERITAS (figure courtesy of TeVCat `http://tevcat.uchicago.edu/`).

3.1 Extragalactic Sources

The catalog of extragalactic sources detected by VERITAS is shown in Table 1. By far the most numerous class of objects are blazars: active galactic nuclei in which the jet is oriented close to the line of sight. Unlike the *Fermi*-LAT, and HAWC, catalog biases due to source selection are unavoidable for

IACTs, which must decide which objects to observe, and for how long, often based on their properties at other wavelengths. Early observations focussed on the blazar sub-class considered most likely to lead to a detection in the energy range above 100 GeV, favoring close ($z < 0.2$) BL Lacertae objects with the peak of their synchrotron emission at high energies (in a νF_ν representation). In more recent years, searches have expanded to include more distant blazars (out to $z > 0.6$, in the case of PKS 1424+240) and those with intermediate- or low-energy synchrotron peaks, such as the eponymous BL Lacertae itself. The most distant sources, as mentioned above, belong to the sub-class of flat-spectrum radio quasars. Only two FSRQs have been detected by VERITAS thus far; searches for additional members of this class are ongoing.

Source	Class	Redshift	Source	Class	Redshift
Markarian 421	HBL	0.031	1ES 0414+009	HBL	0.287
Markarian 501	HBL	0.034	PG 1553+113	HBL	0.4 - 0.62
1ES 2344+514	HBL	0.044	1ES 1440+122	IBL/HBL	0.162
1ES 1959+650	HBL	0.048	B2 1215+30	IBL/HBL	0.130?
H 1426+428	HBL	0.129	BL Lac	LBL	0.0688
1ES 1218+304	HBL	0.182	1ES 0647+250	HBL	0.45?
1ES 0806+524	HBL	0.138	1ES 1011+496	HBL	0.212
W Comae	IBL	0.102	1ES 1727+502	HBL	0.055
3C 66A	IBL	0.33 - 0.41	1ES 1741+196	HBL	0.084
RGB J0710+591	HBL	0.125	1ES 0033+595	HBL	?
PKS 1424+240	IBL	> 0.6	MS 1221.8+2452	HBL	0.218
RGB J0521.8+2112	IBL/HBL	0.108	PKS 1222+216	FSRQ	?
RBS 0413	HBL	0.190	HESS J1943+213	HBL?	?
1ES 0502+675	HBL	0.341?	RGB J2243+203	IBL/HBL	> 0.39
1ES 0229+200	HBL	0.139	PKS 1441+25	FSRQ	0.939
RX J0648.7+1516	HBL	0.179	S3 1227+25	LBL	0.135
M 87	FR I	0.0044	NGC 1275	FR I	0.017559
M 82	Starburst	(3.9 Mpc)			

Table 1 The VERITAS catalog of extragalactic sources (as of June 2015). Blazar sources are listed as HBL, IBL and LBL, where the subclass describes the location of the synchrotron peak in the spectral energy distribution (High-, Intermediate- or Low-energy).

Blazars can be highly variable sources, and the flux is dominated by very broadband non-thermal continuum emission. A critical aspect of blazar studies, therefore, is the need for strictly contemporaneous multi-wavelength coverage. Ideally, this covers the complete spectrum, but overlapping observations are particularly important between the X-ray and gamma-ray bands, where the maxima of the synchrotron and inverse Compton peaks lie, respectively. Coordinated observations with the *Swift* X-ray Telescope and with VERITAS are pre-scheduled and occur almost nightly.

If they are sufficiently close, AGN without aligned jets can also produce measurable gamma-ray emission above 100 GeV. Furthermore, these jets can

be resolved at radio, optical and X-ray wavelengths. Correlating structural changes in the jets with the gamma-ray flux state can potentially provide insights into the particle acceleration and emission processes at work. Two nearby Fanaroff-Riley I radio galaxies have been studied by VERITAS: M 87 (z = 0.004) and NGC 1275 (z = 0.018), at the center of the Virgo and Perseus galaxy clusters, respectively. The M 87 campaign provides an excellent example of the importance of long-term coordinated monitoring with multiple instruments. The source has been regularly monitored by H.E.S.S., MAGIC and VERITAS over the past decade, and has exhibited several flaring episodes. The most dramatic of these occurred in 2010, when a flare lasting a few days was well-sampled by all three instruments (Abramowski et al., 2012) (Fig. 5).

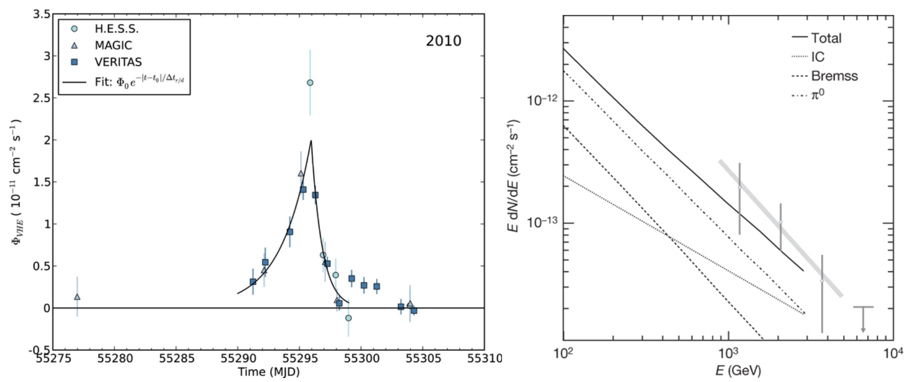

Fig. 5 **Left:** The gamma-ray lightcurve of M 87 during the 2010 flare (Abramowski et al., 2012). **Right:** The gamma-ray spectrum of M 82, compared with a theoretical prediction (Acciari et al., 2009).

Starburst galaxies also form part of the extragalactic observing program for VERITAS. The emission here is thought to be due to interactions of a very dense cosmic ray population with interstellar gas and radiation. Only two such galaxies have been detected by IACTs; M 82 in the north (Acciari et al., 2009) (Fig. 5) and NGC 253 in the south (Acero et al., 2009). The VERITAS detection of M 82 highlights the exceptional background rejection capabilities of IACTs: during 137 hours of observations, over 95 million events were recorded. Following the gamma-ray selection cuts, 99.9997% of the cosmic ray background events were removed, leaving an excess of less than one gamma-ray photon per hour. The corresponding flux is below 1% of the steady flux from the Crab Nebula.

3.2 Galactic Sources

Table 2 lists sources detected by VERITAS which lie within our Galaxy. Results from H.E.S.S. have shown that the population of Galactic TeV sources clusters rather tightly around the inner Galaxy, with the majority confined within $\sim \pm 30^{\circ}$ of the Galactic Centre. This region of the sky is not easily observable by VERITAS (although we make an exception for the Galactic Centre itself). However, the northern sky hosts a number of unique Galactic objects, many of which have been studied in great detail.

Source	Class	Notes
Crab Nebula	PWN	
LS I+61°303	Binary	
IC 443	SNR	
Cas A	SNR	
SNR G106.3+2.7	SNR/PWN	SNR G106.3+2.7 & PWN of PSR J2229+6114?
SNR G54.1+0.3	PWN	
HESS J0632+057	Binary	
Tycho	SNR	
HESS J1857+026	PWN?	
CTA 1	SNR/PWN	
VER J2016+371	PWN	Associated with the PWN CTB 87.
Crab Pulsar	Pulsar	
LS 5039	Binary	
MGRO J1908+06	SNR/PWN	SNR G40.5-0.5 & PWN of PSR J1907+0602?
TeV 2032+4130	PWN	Possible long-period binary (Lyne et al., 2015).
VER J2019+407	Unidentified	Coincident with the gamma-Cygni SNR.
Galactic Centre	Unidentified	Point source, plus extended emission along Gal. Ridge.
VER J2019+368	Unidentified	Inner region of MGRO J2019+37.
SNR G0.9+0.1	PWN	

Table 2 The VERITAS catalog of Galactic sources (as of June 2015). The source class given is not always firmly established - we give the most likely, at the time of writing. Sources are listed in (approximately) the order in which they were detected or published by VERITAS.

First among these is the Crab Pulsar and its nebula. The Crab Nebula was the first TeV source to be established, and has since served as a standard candle for TeV astronomy. The variability, and dramatic flares, recently discovered at lower energies (Abdo et al., 2011), do not appear to extend into the TeV band (Aliu et al., 2014b). Powering the nebula is the Crab Pulsar, which emits over the entire electromagnetic spectrum, before cutting off at 5.8 GeV (Abdo et al., 2010). Observations by VERITAS (Aliu et al., 2011) and MAGIC (Aleksić et al., 2012) have now shown that this cut-off is not sharp - rather, it represents a steepening of the pulsed spectrum, which in fact extends well beyond 100 GeV (Fig. 6). Such high energy emission places

strong constraints on the possible emission zones within the pulsar magnetosphere, and requires substantial revision of existing models.

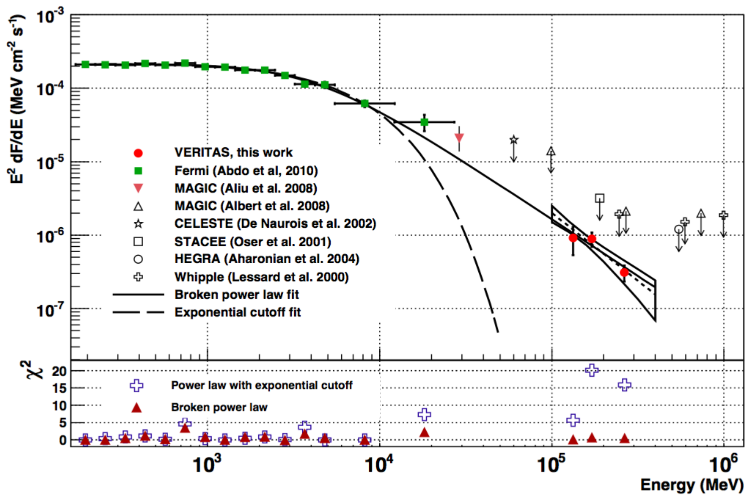

Fig. 6 Spectral energy distribution of the Crab pulsar in gamma rays, showing emission extending as a broken power-law beyond 100 GeV (Aliu et al., 2011).

Among the primary motivations for gamma-ray astronomy at the highest energies has been to search for the sites of Galactic cosmic ray acceleration. Diffusive shock acceleration in the expanding shocks of supernova remnants (SNRs) remains one of the most compelling scenarios. VERITAS has detected TeV gamma-ray emission from a number of remnants, including Tycho's SNR (Acciari et al., 2011a), whose emission above 1 TeV could plausibly be explained by the interactions of high energy protons and subsequent neutral pion decay. The case is far from closed, however, and SNR studies with VERITAS, and the other IACTs, are ongoing. The excellent angular and spectral resolution of the technique is particularly important for this work, allowing morphological studies and spatially resolved spectra for these often extended objects.

Binary systems, consisting of a massive star and a black hole or neutron star companion, have also been observed to emit TeV gamma-rays. The 26.5-day period binary LS I+61°303 has been monitored over the entire lifetime of the VERITAS observatory (Acciari et al., 2008, 2011b; Aliu et al., 2013). Its emission generally peaks around the apastron of the orbit, but is far from persistent - significant detections have been made at other orbital phases, and there is strong evidence for variability between orbits, and possibly even super-orbital modulation, as seen by the LAT (The Fermi-LAT Collaboration, 2013). The source continues to surprise - observations from fall 2014 revealed the brightest flare seen from any gamma-ray binary system to date, exceeding

25% of the Crab Nebula flux (Holder, 2014). HESS J0632+057 is another well-studied system, first detected by H.E.S.S. and firmly identified as a 315-day period binary system through *Swift* X-ray and VERITAS observations (Bongiorno et al., 2011; Aliu et al., 2014a). Modelling of these systems is complicated by the unknown nature of the compact object (and hence the acceleration mechanism), by poorly known orbital ephemerides, and by the changing conditions around the orbit, which lead to strong, energy dependent variations in gamma-ray production and absorption efficiency.

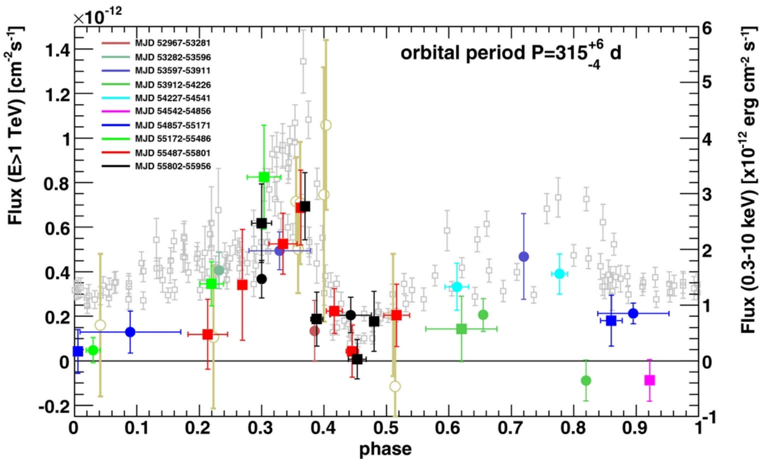

Fig. 7 The TeV gamma-ray and *Swift* X-ray light curve of HESS J0632+057, folded by the 315-day orbital period (Aliu et al., 2014a).

3.3 Astroparticle Physics and Cosmology.

Studying the properties of astrophysical gamma-ray sources provides insight into the mechanisms of particle acceleration and gamma-ray production in a wide range of environments. The science goals of gamma-ray astronomy go far beyond this, however, addressing many topics in astroparticle physics and cosmology. Long-term VERITAS observing campaigns contribute to these goals, and are ongoing.

Extragalactic sources, in particular, can be used as tools to probe intergalactic photon fields (e.g. Archambault et al. (2014b)) and intergalactic magnetic fields. Sources at the highest redshift provide the most sensitive searches for evidence of secondary photon production, for example through cosmic ray induced cascades along the line of sight, or through the oscillations of axion-like particles (e.g. Archambault et al. (2014a)). Gamma-ray obser-

vations of Galaxy clusters provide constraints on the cosmic ray density and magnetic field strength in these regions, as well as on the self-annihilation cross-section for dark matter particles (Arlen et al., 2012). Also high on the list of dark matter targets are dwarf spheroidal galaxies, which provide constraining limits with very little possibility of a contaminating gamma-ray background from more prosaic astrophysical mechanisms (Aliu et al., 2012; Acciari et al., 2010).

Other topics under study include cosmic ray measurements, searches for violations of Lorentz invariance (Zitzer et al. , 2013), and searches for gamma-ray emission from evaporating black holes (Tešić et al., 2012). The recent results from IceCube have opened a new area of study, in the search for a gamma-ray counterpart which would allow to identify the sources of high energy astrophysical neutrinos. Figure 8 shows the published IceCube events, with two of the locations already observed by VERITAS indicated. The gamma-ray observations have produced only upper limits so far, but programs are in development to provide near real-time alerts which will allow for more rapid VERITAS follow-up.

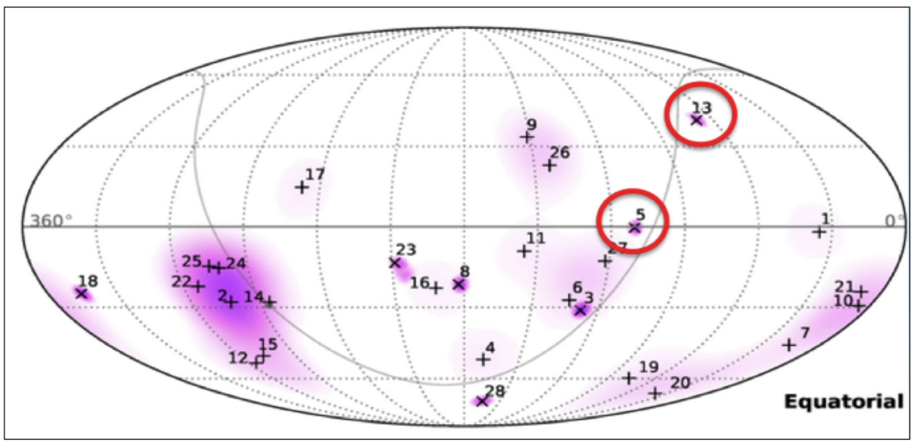

Fig. 8 The IceCube skymap of astrophysical neutrino candidates, from Aartsen et al. (2014). The red circles indicate two of the well-located muon-track events in the northern hemisphere which have been observed with VERITAS.

4 VERITAS and HAWC

We conclude with some comments on the status of collaboration between VERITAS and HAWC, which holds much promise for the future of gamma-ray astronomy in the northern hemisphere. VERITAS, at 31°40′ N 110°57′

W, and HAWC, at 18°59′ N 97°18′ W, are situated reasonably close to each other (a mere 1539-mile drive!). This allows both observatories to view almost the same region of the celestial sphere at exactly the same time. The strength of HAWC lies in its continuous operation and large field of view. VERITAS complements these with excellent instantaneous sensitivity, and good angular and spectral resolution. HAWC results can be used to help guide the VERITAS observing program. VERITAS can provide high resolution imaging and spectra of steady and/or extended HAWC sources, and rapid, time-resolved follow-up of flaring sources.

Figure 9 highlights the typical regions of exposure available to both HAWC and VERITAS, in Galactic coordinates. The shaded region of the upper skymap indicates declination from 0° to 60°, all of which is easily and continuously visible to HAWC. The red point shows the approximate size of the field-of-view of VERITAS. The lower plot shows the accumulated exposure, in hours, of one full year of VERITAS observations. Note that most of these exposures are short ($<$ 5 hours) - often corresponding to brief “snapshot” observations of time-variable sources such as blazars.

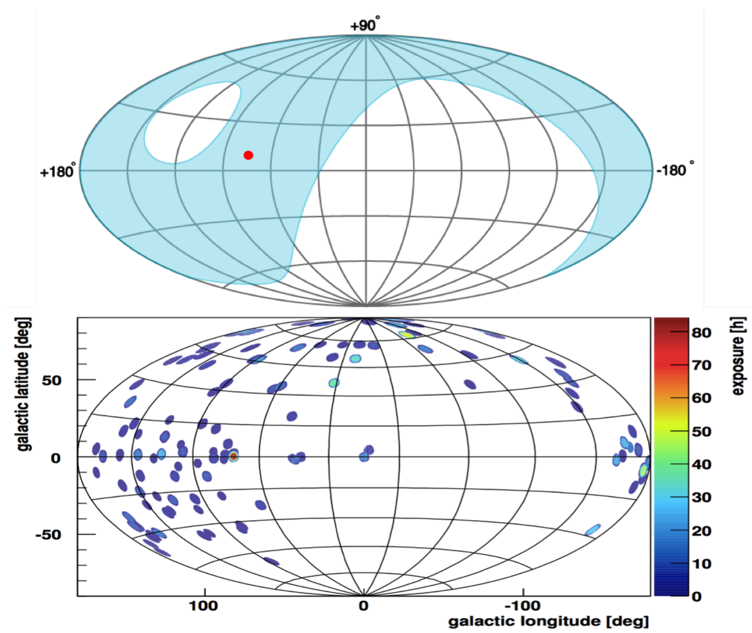

Fig. 9 **Top:** The shaded region indicates declination from 0° to 60° - the approximate field-of-view of HAWC; the red point shows the size of the field-of-view of VERITAS. **Bottom:** The accumulated exposure, in hours, of one full year of VERITAS observations.

Figure 10 shows measurements of the Crab Nebula with VERITAS. A point source with the same flux and spectrum as the Crab is detected at

a significance of $4-5\sigma$ after just 1 minute of observation. 5 minutes gives a 10σ detection, and a well-resolved spectrum. After a typical 30-minute exposure, the significance stands at 25σ - sufficient to measure secondary spectral and morphological features (spectral cut-offs and small-scale source extensions, for example). This excellent instantaneous sensitivity allows the study of bright flaring sources on very short timescales, as demonstrated by the lightcurve of a bright flare from Markarian 421 in Figure 11. For the brightest flaring activity, the lightcurve is resolved into 2-minute time bins, the signal in each of which is highly significant.

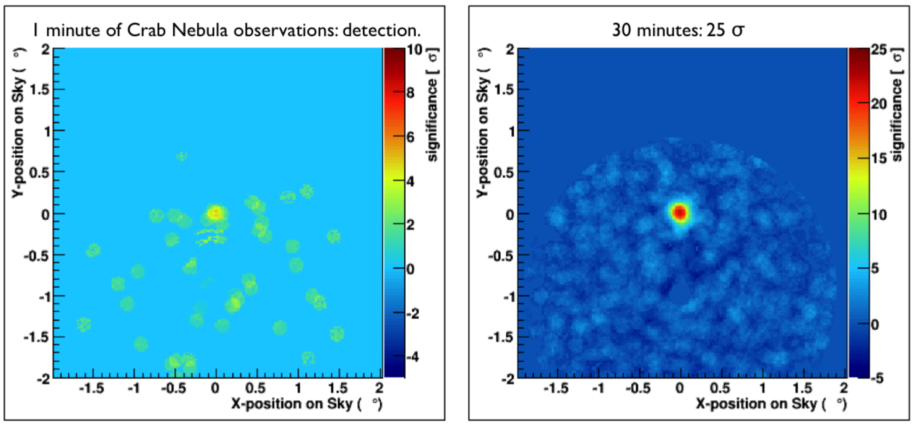

Fig. 10 Observations of the Crab Nebula on different timescales with VERITAS.

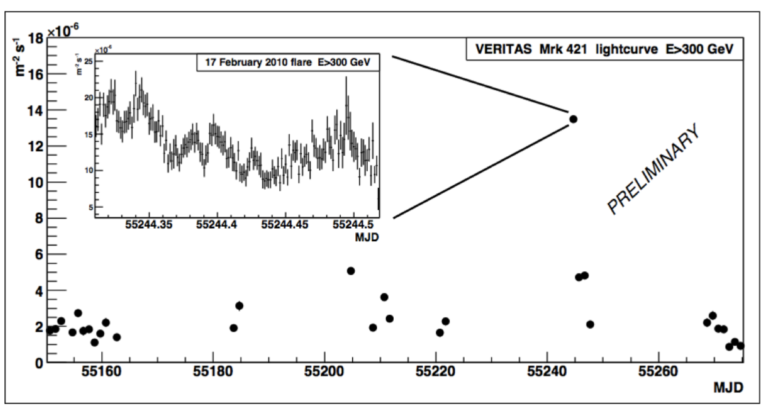

Fig. 11 VERITAS observations of a bright flare from the blazar Markarian 421 in 2010 (Galante, 2011).

The ability of VERITAS to resolve extended sources, and to discriminate between sources in confused regions, is illustrated in Figure 12, which shows VERITAS observations (Aliu et al., 2014c) of the inner region of an extended TeV source first identified by Milagro (Abdo et al., 2012). VERITAS resolves two distinct sources, one of which overlaps with the PWN CTB 87. A larger, 1° extended region of emission is also resolved, which is notably coincident with the pulsar PSR J2021+3651 and with the star formation region Sh 2-104. While these results (and similar resolved maps of MGRO J1908+06, and TeV 2032+4130, for example) are impressive, it is worth noting that morphological studies such as this require a significant investment of time - the MGRO J2019+37 field required over 70 hours, collected over multiple observing seasons. This point is important in the context of IACT follow-up observations of new HAWC sources, which will also likely be weaker than Milagro sources. Timely exchange of information between the collaborations will be necessary, to allow collection of a sufficiently large exposure by VERITAS.

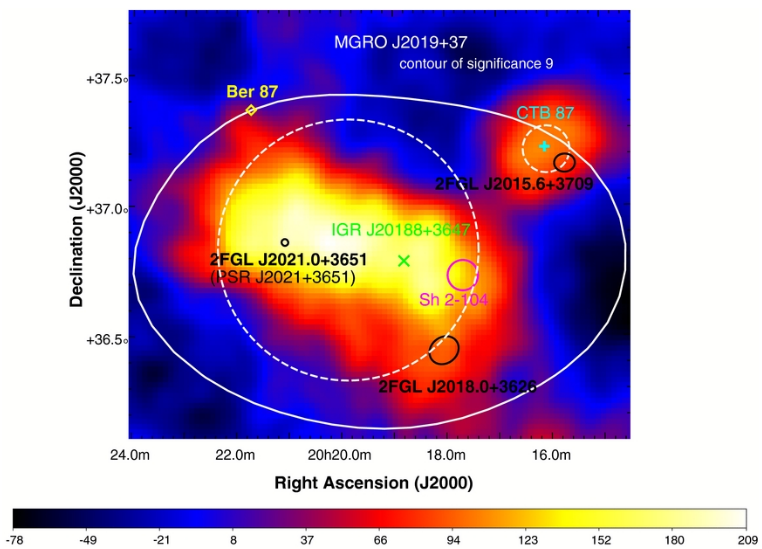

Fig. 12 The MGRO J2019+37 region as observed by VERITAS above 600 GeV. The contour of significance 9 of MGRO J2019+37 is overlaid in white (Aliu et al., 2014c).

Co-operation and collaboration between HAWC, VERITAS, and the other gamma-ray observatories is already underway. A memorandum of understanding between HAWC and VERITAS has been signed, allowing for rapid communication of results prior to publication. HAWC has joined an existing "Bright AGN alert" network, which is used to notify the gamma-ray observatories of bright flares from known TeV sources. A series of meetings has been established between Fermi, VERITAS and HAWC, with meetings at UMD and Wisconsin - the next in this series will be held in Utah in the coming

year. HAWC members are collaborating with VERITAS members to propose VERITAS observations, and sub-groups are forming to study specific topics of overlapping science. Collaboration such as this will allow us to make the best use of these powerful and complementary techniques for exploring the high-energy Universe.

Acknowledgements The research summarized in this report is supported by grants from the U.S. Department of Energy Office of Science, the U.S. National Science Foundation and the Smithsonian Institution, and by NSERC in Canada. We acknowledge the excellent work of the technical support staff at the Fred Lawrence Whipple Observatory and at the collaborating institutions in the construction and operation of the instrument. J. Holder acknowledges the support of NSF award number PHY-1403336.

The VERITAS Collaboration is grateful to Trevor Weekes for his seminal contributions and leadership in the field of VHE gamma-ray astrophysics, which made this work possible.

References

Aartsen, M. G., Ackermann, M., Adams, J., et al. 2014, Physical Review Letters, 113, 101101
Abdo, A. A., Ackermann, M., Ajello, M., et al. 2010, ApJ, 708, 1254
Abdo, A. A., Ackermann, M., Ajello, M., et al. 2011, Science, 331, 739
Abdo, A. A., Abeysekara, U., Allen, B. T., et al. 2012, ApJ, 753, 159
Abramowski, A., Acero, F., Aharonian, F., et al. 2012, ApJ, 746, 151
Acciari, V. A., Beilicke, M., Blaylock, G., et al. 2008, ApJ, 679, 1427
Acciari, V. A., Aliu, E., et al. 2009, Nature, 462, 770
Acciari, V. A., Arlen, T., Aune, T., et al. 2010, ApJ, 720, 1174
Acciari, V. A., Aliu, E., Arlen, T., et al. 2011a, ApJL, 730, L20
Acciari, V. A., Aliu, E., Arlen, T., et al. 2011b, ApJ, 738, 3
Acero, F., Aharonian, F., Akhperjanian, A. G., et al. 2009, Science, 326, 1080
Aleksić, J., Alvarez, E. A., Antonelli, L. A., et al. 2012, A&A, 540, A69
Aliu, E., Arlen, T., et al. 2011, Science, 334, 69
Aliu, E., Archambault, S., Arlen, T., et al. 2012, Phys. Rev. D., 85, 062001
Aliu, E., Archambault, S., Behera, B., et al. 2013, ApJ, 779, 88
Aliu, E., Archambault, S., Aune, T., et al. 2014a, ApJ, 780, 168
Aliu, E., Archambault, S., Aune, T., et al. 2014b, ApJL, 781, L11
Aliu, E., Aune, T., Behera, B., et al. 2014c, ApJ, 788, 78
Archambault, S., Aune, T., Behera, B., et al. 2014a, ApJL, 785, L16
Archambault, S., Arlen, T., Aune, T., et al. 2014b, ApJ, 788, 158
Arlen, T., Aune, T., Beilicke, M., et al. 2012, ApJ, 757, 123
Bongiorno, S. D., Falcone, A. D., Stroh, M., et al. 2011, ApJL, 737, L11
The Fermi-LAT Collaboration 2013, arXiv:1307.6384
Galante, N. 2011, International Cosmic Ray Conference, 8, 63
Holder, J. 2014, The Astronomer's Telegram, 6785, 1
Kieda, D. 2011, International Cosmic Ray Conference, 9, 14

Lyne, A., Stappers, B., Keith, M., et al. 2015, arXiv:1502.01465

McCann, A., Hanna, D., Kildea, J., & McCutcheon, M. 2010, Astroparticle Physics, 32, 325

Mirzoyan, R. 2015, The Astronomer's Telegram, 7416, 1

Mukherjee, R. 2015, The Astronomer's Telegram, 7433, 1

National Research Council Astronomy and Astrophysics Survey Committee 2000, Astronomy and Astrophysics in the New Millennium Publisher: National Academy Press, Washington DC., 2000.

Perkins, J. S., Maier, G., & The VERITAS Collaboration 2009, arXiv:0912.3841

Tešić, G., & VERITAS Collaboration 2012, Journal of Physics Conference Series, 375, 052024

Weekes, T. C., 165th AAS Meeting, Tucson, Arizona, 1984

Zitzer, B., & for the VERITAS Collaboration 2013, arXiv:1307.8382